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Climate Risks and Land Cover Dynamics of the Dibalo-Pingit-Zabali-Malayat River Watershed in Aurora, Philippines

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Abstract

This study investigates the complex interplay between climate-related hazards and land cover changes in the Dibalo-Pingit-Zabali-Malayat (DPZM) River Watershed of Aurora province, Philippines. Historical typhoon data underscore the region's vulnerability to extreme weather events, emphasizing the critical need to enhance disaster preparedness and management. Land cover analysis from 1988 to 2020 reveals substantial transformations, driven largely by agricultural expansion at the expense of forest cover. Specifically, closed forest areas decreased by 11% annually from 2010 to 2015, while open forest areas decreased by 31% from 1988 to 2003. Conversely, built-up areas, annual crops, and perennial crops increased by 3%, 9%, and 30%, respectively, reflecting growing human pressures from 1988 to 2003. These land cover changes have intensified watershed degradation, as evidenced by increasing landscape fragmentation and declining mean patch size. Such alterations heighten the watershed susceptibility to natural hazards and hinders its capacity to provide essential ecosystem services. The study underscores the urgency for science-informed watershed management strategies to mitigate climate risks and protect the livelihoods of communities reliant on the DPZM River Watershed. Prioritizing sustainable land use practices, forest restoration, and disaster preparedness is crucial for safeguarding the watershed's ecological integrity and resilience in the face of ongoing challenges.

Keywords

Land cover change; Climate risks; Watershed management; Disaster preparedness

Introduction

Watersheds, composed of various interacting ecosystems from upland to the lowland, play a critical role in safeguarding vital ecosystem

services against climate changes and extreme weather events. (Rodeo et al., 2019). Thus, watersheds are widely susceptible to such risks which will significantly affect surrounding communities, impacting everything from water resources to local economy.

The Dibalo-Pingit-Zabali-Malayat (DPZM) River Watershed Forest Reserve in Aurora province exemplifies this vital role. Established in 1992 as a protected area (Proclamation 908 dated May 25, 1992) this 14,330 hectares watershed safeguard water resources and prevents unsustainable forest exploitation. The DPZM River Watershed is a critical ecosystem providing essential services to upstream and downstream communities. However, located in one of the most climate vulnerable countries of the world, the Philippines, Aurora province is facing various kinds and magnitude of climate risks considering its geographical location, and other environmental, economic and social stressors. These challenges are compound by human activities that put strain on DPZM river watershed resilience, threatening the sustainability of water resources and other vital goods and services it provides to province and the entire country. As Meybeck *et al.* (2003) points out, anthropogenic pressures have significantly alter river systems affecting their ability to provide ecosystem services.

Climate change plays an important role in shaping the ecological stability of landscape systems (Prokopova *et al*., 2019). While protected and well-managed watersheds can help reduce vulnerability to climate hazards, these areas themselves are also susceptible (MacKinnon, Dudley and Sandwith, 2011). Climate hazards such as typhoon, flood, and increasing weather fluctuations such as droughts threatens the resilience of a social-ecological system like watershed.

Land use and land cover change (LULC) can portray the pattern of human land use in a particular system and plays an important role in soil and water conservation (Chang, *et al*., 2018). Studying how land use patterns change globally is essential to cope with climate change and achieving sustainable development. Land cover change caused by human activities such as deforestation, urbanization, agricultural expansion, and resource extraction are drivers of land cover change that affects the conditions of watersheds and negatively influences ecosystem services (Huang *et al*., 2019). Land-use change is a primary driver of climate change and variability (IPCC, 2014), which, in turn, accelerates further land-use alterations like desertification and glacier retreat. Moreover, the increased frequency of extreme weather events, such as droughts and floods, can be attributed to interactions between climate and land-use dynamics (IPCC, 2014).

The interplay between climate risks and land use change is a complex and rapidly evolving field. However, this great interplay is understudied (Lunyolo, Khalifa and Ribbe, 2020). This study, therefore, explores this interaction in a watershed for the period between 1988 and 2020. Studying land cover dynamics is crucial for understanding the impact of human activities on the environment. By analyzing historical data and using remote sensing techniques, scientists can track LULC trends. This knowledge allows us to predict future changes and develop sustainable watershed management and minimize negative environmental impacts and ensure the long-term health of our planet.

This study is aimed to achieve the following objectives:

- To identify the climate-related risks in the study area;

- To examine the historical trend of land use and land cover change in the study area; and
- To assess the complex interplay between climate-related hazards and land cover changes in DPZM River watershed.

Methodology

Description of the Study Area

The study was conducted from 2021-2023 in the Dibalo-Pingit-Zabali-Malayat (DPZM) River Watershed located on the eastern coast of Luzon at coordinates 121^0 34' 22.8" east longitude and 15^0 41' 40.46" north latitude (Figure 1). It is bounded to the north by the Dipaculao, northeast by the Baler Bay which is the outlet, southwest by the Mt. Dingalan, and northwest by the Aurora Memorial Natural Park. This 14,330-hectare watershed spans 24 barangays across the municipalities of Baler and San Luis in Aurora province (Table 1). The municipality of Baler encompasses approximately 40% of the watershed area which covers 10 barangays, while San Luis municipality covers the remaining 60%.

The DPZM watershed was chosen for this study despite being a protected landscape because of its ongoing challenges of deforestation and forest degradation. Additionally, the watershed experiences intense rainfall and high vulnerability to flooding, landslide and soil erosion (DENR, 2023).

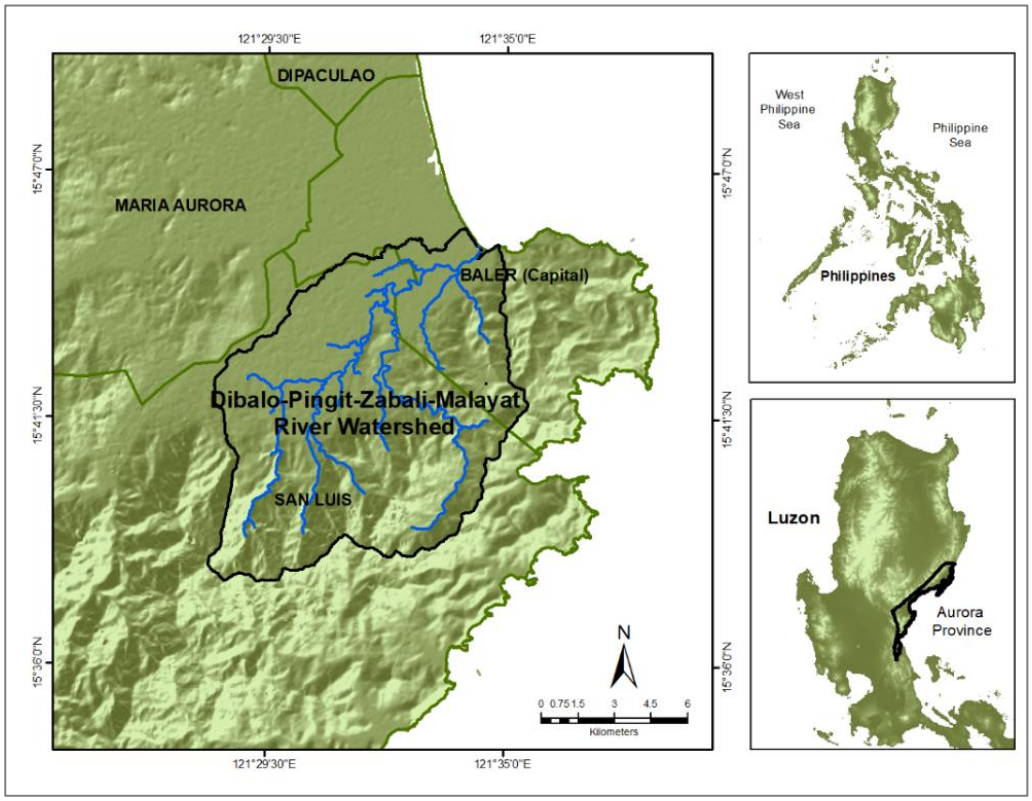

Figure 1: Location map of DPZM River Watershed

Table 1: Barangays covered by the DPZM Watershed Forest Reserve.

Municipality	*Barangay*	*Classification*	*Area (ha) within the watershed*	*% Area*
Baler	Barangay I	Rural	2	0.01
	Barangay II	Rural	24	0.2
	Barangay III	Rural	13	0.1
	Barangay IV	Rural	17	0.1
	Barangay V	Urban	44	0.3
	Calabuanan	Rural	523	4
	Pingit	Rural	3,460	24
	Sabang	Rural	136	1
	Suclayin	Rural	97	1
	Zabali	Rural	1,351	9
Subtotal			*5,667*	*40*
San Luis	Bacong	Rural	2	2
	Barangay I	Urban	36	0.3
	Barangay II	Urban	46	0.3
	Barangay III	Rural	47	0.3
	Barangay IV	Rural	95	1
	Dibalo	Rural	1,081	8
	Dibut	Rural	3,295	23
	Ditumabo	Urban	10	0.1
	L. Pimentel	Rural	2	7
	Nonong Senior	Urban	1,873	13
	Real	Rural	238	2
	San Isidro	Rural	107	1
	San Jose	Rural	266	2
	Zarah	Rural	185	1
Subtotal			*8,663*	*60*
Grand Total			14,330	100

Source: Aurora Province and University of the Philippines Los Banos, 2023

Research Approach and Design

Before commencing to the actual research, the research team initiated courtesy visits to relevant government offices. These include the Local Government Units (LGUs) of Baler and San Luis, the Provincial Environment and Natural Resources Office (PENRO), and the Community Environment and Natural Resources Office (CENRO). Following the necessary procedures, permission was obtained to ensure proper authorization to conduct research. The study employed a mixed method approach, utilizing both qualitative and quantitative data collection methods for primary and secondary data sources. This approach involves key informant interviews with the staff from LGUs, PENRO, CENRO, Provincial Government of Aurora, and Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) in Baler, and UP Resilience Institute to gain valuable insights into the study area.

The LULC data were sourced from the National Mapping and Resource Information Authority (NAMRIA), the German Technical Cooperation Agency (GTZ), and the Food and Agriculture Organization (FAO). Details of the LULC series as presented by Santos in 2018, were provided by NAMRIA (Table 1).

Geospatial data are reliable sources for determining and understanding the drivers of LULC changes at any landscapes (Ramirez *et al*., 2019). In this paper, satellite images used for LULC maps from GTZ and NAMRIA representing land cover classes of Dipaculao-Pingit-Zabali-Malayat River Watershed Forest Reserve from 1988 to 2020 were obtained. For 1988 land cover data, Landsat TM data from 1982 to 1985 were processed and supported by ground measurement conducted by the Bureau of Forest Development (BFD) with the assistance from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and Food and Agriculture Organization (FAO). The 2010 land cover map was sourced from Landsat 7 ETM+ data from 2010 with 30-m resolution and classified based on FAO-FRA Project Field Inventory Manual with NAMRIA and Forest Management Bureau (FMB) collaboration; ALOS AVNIR-2 (10 m resolution), SPOT 5 (10 m resolution) and Landsat 7 ETM+ (30 m resolution). Data were validated on the ground with accuracy assessment (calculated by province through overlaying the ground validated sample data over the preliminary map and presented the success or failure of the matches in Confusion matrix with overall accuracy of 89%). Landsat operational land imager (OLI) data from 2015 was used, with 30 m resolution with reference data from Google Earth Pro, topographic maps, ground truth data and Interferometric Synthetic Aperture Radar (IFSAR) data for coastline using OBIA eCognition software for digital classification with ground validation and accuracy assessment of 93.92% (Santos, 2018). These four land cover maps were presented and validated in the Department of Environmental and Natural Resources (DENR) regional and provincial offices, local government units (LGUs), and selected stakeholders. Moreover, these LULC maps are recognized maps by the Philippine Government that can be used by the national government offices, academe and other organizations/institutions (Ramirez *et al*., 2019).

The 1988 Landsat imageries, along with aerial photographs and ground measurement which were taken in 1982 to 1985, were processed and generated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and the Food and Agriculture Organization (FAO), and the Bureau of Forest Development (BFD). Although the classification and validation methods at that time were not well-documented, the 1988 land cover data serves as a critical baseline for that period. This baseline is essential for understanding the initial condition of the Dibalo-Pingit-Zabali-Malayat River Watershed, allowing for the visualization and assessment of the landscape and climate impacts over time. By comparing this 30-year land cover data with subsequent information and official maps from NAMRIA, researchers, national government agencies, local government units, local organizations and major stakeholders can identify trends and changes resulting from watershed programs and projects initiatives.

A reclassification scheme of seven classes were applied based on physical knowledge of the area, and visual interpretation using historical function of Google Earth Pro. The eight LULC classes were categorized as annual crop, built-up area, closed forest, open forest, perennial crop, mangrove forest, grassland/shrubs and inland water (Table 2).

Table 2: Reclassified land use/land cover classes for Dipaculao-Pingit-Zabali-Malayat River Watershed Forest Reserve, Baler and San Luis, Aurora.

LULC Class	*Description* [a]
Annual crop	Land cultivated with crops with a growing cycle under one year, which must be newly sown or planted for further production after harvesting
Built-up area	Composed of areas of intensive use with much of the land covered with structures. It includes cities, towns, villages, strip development along highways, transportation, power and communication facilities, and areas occupied by mills, shopping centers, industrial and commercial complexes, recreations areas and institutions.
Closed forest	Formations where trees in the various storeys and the undergrowth cover a high proportion (>40%) of the ground and do not have a continuous dense grass layer. They are either managed or unmanaged forest, primary or in advanced state of reconstitution and may have been logged-over one or more times, having kept their characteristics of forest sands, possibly with modified structure and composition.
Open forest	Formation with discontinuous tree layer but with a coverage of at least 10% and less than 40%. Generally, there is a continuous grass layer allowing grazing and spreading of fires.
Perennial crop	Cultivated with long-term crops that do not have to be replanted for several years after each harvest; harvested components are not timber but fruits and other products that do not significantly harm the growth of the planted trees or shrubs. Can be orchards, vineyards, and plantations of palm, coffee, tea, sisal, banana, abaca, etc.
Mangrove forest	Forested wetland growing along tidal mudflats and along shallow water coastal areas extending inland along rivers, streams, and their tributaries where the water is generally brackish and composed mainly of *Rhizophora*, *Bruguiera*, *Ceriops*, *Avicennia*, and Nipa species.
Grassland/Shrubs	Lands predominantly vegetated with grasses, devoid of trees or with very few isolated trees. Shrubs refer to woody plant that is typically less than 8 meters tall
Inland water	Bodies of water surrounded by land (e.g., rivers, lakes, streams, fish pens/cages, dams, and reservoirs)

[a]FAO, 2000 (Global Forest Resources Assessment), and NAMRIA, undated

Fragmentation analysis using Landscape Metrics

Application of spatial metrics allows to determine the composition and spatial configuration of landscapes and patch elements at a certain point in time (Garcia *et al*., 2020; Kamusoko and Aniya, 2007; McGarigal, Cushman and Ene, 2012; Tolessa, Senbeta and Kidane, 2016; Wu *et al*., 2011). According to Robeson, Thapa and Saikia (2016), the most important indicators of landscape fragmentation are the number of

patches, and the change in the smaller patches, as measured by patch density (Echeverria *et al*., 2006; Kammerbauer and Ardon, 1999; Southworth, Munroe and Nagendra, 2004). To monitor land cover changes, number of patches (NP), MPS (Mean Patch Size), ED (Edge Density) and Perimeter-area Fractal Dimension (PAFRAC) were used to determine the trend from 1988 to 2020 (Table 3).

Table 3: Spatial metrics used in the Dipaculao-Pingit-Zabali-Malayat River Watershed Forest Reserve.

Metric	*Description*	*Unit/Value range*
Number of Patches (NP)	Total number of patches. It is a fragmentation Index. Higher the value more the fragmentation	NP>0, without limit
Mean Patch Size (MPS)	Equals the average area of all patches of a particular patch type	Ha
Edge Density (ED)	Total length of edge of a certain LULC class per unit area (m/ha)	m/ha
Perimeter-area Fractal Dimension (PAFRAC)	Indicates the relationship between the area and perimeter of the patches. Values approaches 1 for shapes with very simple perimeters, and approaches 2 for shapes with highly complex perimeters	1≤PAFRAC C≤2

Source: McGarigal, Tagil and Cushman, 2009, Landscape Ecology Journal; McGarigal, Cushman and Ene, 2012, FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps.

Change Rate/Annual Rate of Change

Annual rate of change was also calculated using the rate formula (Batar, Watabe and Kumar, 2017; Puyravaud, 2003; Teferi *et al*., 2013):

$$r = \left[\frac{1}{t2-t2}\right] \times \ln\left(\frac{A2}{A1}\right)$$

where, *r* is the annual rate of change for each class, and A_1 and A_2 are areas of each LULC class at time t_1 and t_2, respectively.

Results and Discussion

Historical Climate Hazards in the Philippines

Secondary information obtained from the National Disaster Risk Reduction and Management Council website (Table 5) offers a comprehensive overview of the significant climate-related hazards and typhoons that have affected Aurora province within Region III from 2000 to 2023. The analysis reveals a concerning trend, with a total of 93 typhoons highlighting the vulnerability of the province to these storms. The typhoons resulted to recurring instances of flooding and rain-induced landslides. Additionally, typhoons also brought severe winds and heavy rainfall, occasionally leading to storm surges recorded 18 times between 2000 and 2023.

These typhoons have had a profound impact on Aurora province particularly in DPZM River Watershed. The hazards have caused widespread damage to homes, buildings, agricultural lands, and transportation infrastructure like roads and bridges. Power outages and the suspension of classes have further exacerbated the socio-economic disruptions. Four major typhoons - Unding, Violeta, Winnie, and Yoyong - in 2004, inflicted extensive damage on both the physical and social landscapes of Aurora province. These events highlight the vulnerability of Aurora, particularly the DPZM River Watershed, to typhoon-induced hazards. This underscores the urgent need for improved disaster preparedness and management strategies.

Table 5: Trends in typhoon occurrence in the Philippines from 2000 – 2023 particularly affecting Aurora province

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
Flood/ Rain-induced landslide (RIL)/Severe Winds	Super Typhoon Egay (Doksuri) and Typhoon Falcon (Khanun)	July 21 - August 4, 2023	Region I, Region II, Region III, CALABARZON, MIMAROPA, Region V, Region VI, Region VIII, Region XII, BARMM
Flood/ Rain-induced landslide/Severe Winds	Southwest Monsoon enhanced by Tropical Storm Dodong (Talim)	July 12-17, 2023	Region I, III, CALABARZON, MIMAROPA, Region VI, NCR
Flood/ Rain-induced landslide /Severe Winds	Super Typhoon Betty (Mawar)	May 20 - June 1, 2023	Region I, II, III, MIMAROPA, Region VI, VII
Flood/Rain-induced landslide	Tropical Depression Amang	April 10-13, 2023	Region III, V, CALABARZON
Flood/ Rain-induced landslide/Severe Wind/Storm Surge	Severe Tropical Storm Paeng (Nalgae)	October 25-31, 2022	Regions I, II, CAR, III, NCR, CALABARZON, MIMAROPA, V, VI, VII, VIII, IX, X, XI, XII, BARMM, CARAGA
Flood/Rain-induced landslide	Super Typhoon Karding (Noru)	September 22-26, 2022	Region I, II, III, CALABARZON, MIMAROPA, V, CAR, NCR RIL - Brgy. Aluyon, Quezon; Bimmangko/Antutot, Kasibu, Nueva Viscaya; Benihal-Napo Road, Ambaguio, Nueva Viscaya; HolangCudof-Mungayang Provincial Road, Bayyucan-Caba Provincial Road, Lagawe, Ifugao Flood - Pampanga, Bulacan, Rizal, Laguna, Cavite, Quezon, Camarines Sur

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
Flood/Rain-induced landslide /Mudslide/ Erosion	Super Typhoon Henry (Hinnamnor)	August 31-September 4, 2022	Region I, III, CAR; Mudslide - Bacsil, San Fernando; RIL - Brgy. Pao Norte, Brgy Cabarsican, San Fernando; Brgy. Alibangay, Bagulinl Up-uplas, Sudipen; Tuding, Itogon; Pacdal, Baguio; Flood - Biday, San Fernando; KM4, Poblacion and Betag, Pico, Beckel, Cogcoga, Balili, La Trinidad; San Roque, Baguio; Erosion - Amduntog, Asipulo; Poblacion, Bahong, Beckel; Dontogan, Irisan, Baguio, Leonila Hill; Imelda Village, Baguio
Flood/Rain-induced landslide /Severe Wind	Severe Tropical Storm Florita (Ma-on)	August 21-24, 2022	Regions I, II, III, CALABARZON, V, CAR, NCR
Flood/Severe Wind/Storm Surge/ Rain-induced landslide	Severe Tropical Storm Maring (Kompasu)	October 7-13, 2021	Regions I, II, CAR, III, CALABARZON, MIMAROPA, VI, CARAGA; Landslide and Flood - La Trinidad, Benguet
Flood/ Rain-induced landslide	Typhoon Kiko (Chantu)	September 7-12, 2021	Regions I, II, III, MIMAROPA, CAR
Flood/Severe Wind/ Rain-induced landslide	Typhoon Jolina (Conson)	September 6-9, 2021	Regions III, CALABARZON, MIMAROPA, V, VI, VII, VIII
Flood/Storm Surge/ Rain-induced landslide/Severe Wind	Typhoon Fabian (IN-FA)	July 19-24, 2021	Regions I, II, III, VI, CALABARZON, MIMAROPA, CAR, NCR
Rain-induced landslide /Flood	Combined Effects of ITCZ and Tropical Storm Dante (Choi-Wan)	May 25 - June 5, 2021	Regions I, III, V, VI, VII, VIII, XI, XII, CALABARZON, MIMAROPA, CARAGA, BARMM
Flood/Severe Wind/ Rain-induced landslide/Storm Surge	Typhoon Ulysses (Vamco)	November 9- 14, 2020	Regions I, II, III, CALABARZON, MIMAROPA, V, CAR, and NCR
Rain-induced landslide /Flood/Storm Surge	Typhoon Quinta (Molave)	October 23-27, 2020	Regions III, CALABARZON, MIMAROPA, V, VI, VII, VIII
Rain-induced landslide/Flood	Typhoon Pepito (Saudel)	October 19-22, 2020	Regions II, CAR, III, CALABARZON, NCR
Rain-induced landslide	Tropical Storm Butchoy (Nuri)	June 11-13, 2020	Regions I, II, III, CALABARZON, MIMAROPA, V, VI, VII, VIII, NCR, CAR

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
Rain-induced landslide /Flood	Typhoon Ambo (Vongfong)	May 10-15, 2020	Regions I, II, III, VIII, CAR
Rain-induced landslide /Flood	Typhoon Rosita (Yutu)	October 27-November 2, 2018	Northern Samar; Regions I, II, III, CAR, CALABARZON
Rain-induced landslide /Flood/Severe Wind	Typhoon Ompong (Mangkhut)	September 12-15, 2018	Regions I, II, III, CAR, CALABARZON, MIMAROPA, NCR;
Rain-induced landslide /Flood	Southwest Monsoon Enhanced by Tropical Depression Luis	August 23 - September 3, 2018	Regions I, III, CAR
Rain-induced landslide /Flood	Southwest Monsoon Enhanced by Tropical Storm Karding (Yagi)	August 13-26, 2018	Regions I, II, III, CAR, CALABARZON, NCR
Flood/Rain-induced landslide	Southwest Monsoon (*Habagat*) enhanced by Typhoon Gorio (Nesat) and Tropical Storm Huaning (Haitang)	July 25-31, 2017	Regions I, III, CALABARZON, MIMAROPA, CAR, and NCR. Flood - Regions I, III, NCR. Flashflood - Regions III, CAR. Landslide - Regions I, CALABARZON, MIMAROPA, CAR, NCR
Flood/Severe Wind/ Rain-induced landslide	Super Typhoon Lawin (Haima)	October 17-20, 2016	Regions I, II, III, CALABARZON, V, CAR
Flood/Severe Wind/ Rain-induced landslide	Typhoon Karen (Sarika)	October 13-17, 2016	Regions I, II, III, CALABARZON, V, CAR
Rain-induced landslide /Flood/Severe wind/Storm Surge	Typhoon Lando (Koppu)	October 14-21, 2015	Regions I, II, III, CALABARZON, NCR and CAR
Flood/ Rain-induced landslide	Typhoon Ineng (Goni)	August 18-23, 2015	Regions CAR, I, II, III, CALABARZON, MIMAROPA
Flood/Severe Wind	Typhoon Ruby (Hagupit)	December 4-10, 2014	Regions III, IV-A, IV-B, V, VI, VII, VIII, CARAGA, NCR
Rain-induced landslide /Flood	Tropical Storm Mario (Fung-wong)	September 17-22, 2014	
Rain-induced landslide /Flood	Typhoon Luis (Kalmaegi)	September 12-15, 2014	Regions I, II, III, CALABARZON, MIMAROPA, VI, CAR, NCR
Rain-induced landslide /Flood/Severe wind	Typhoon Glenda (Rammasun)	July 13-17, 2014	Regions I, III, CALABARZON, MIMAROPA, V, VIII, and NCR
Rain-induced landslide /Flood/Severe wind/Storm Surge	Typhoon Odette (Usagi)	September 16-22, 2013	Regions I, III, IV-A, IV-B, V, VI, CAR

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
Flood/ Rain-induced landslide/Storm Surge	Typhoon Labuyo (Utor)	August 9-12, 2013	Regions I, II, III, MIMAROPA, V, VI, VII, CAR
Flood/ Rain-induced landslide /Tornado	Tropical Storm Ofel (Son-Tinh)	October 22-26, 2012	Regions III, IV-A, IV-B, V, VI, VII, VIII, IX, XII, CAR, CARAGA
Flood/Storm Surge	Tropical Storm Marce (Gaemi)	October 1-6, 2012	Regions III, IV-B
Flood/ Rain-induced landslide	Tropical Depression Karen (Sanba)	September 11-15, 2012	Regions III, VIII, NCR; Landslide: Brgy. Mugto, Habangan, Samar
Flood/ Rain-induced landslide	Tropical Depression Helen (Kai-tak)	August 11-16, 2012	Regions I, II, III, IV-B, CAR
Rain-induced landslide /Flood/Storm Surge	Typhoon Gener (Saola)	July 28-August 2, 2012	Regions I, II, III, IV-A, IV-B, V, VI, VII, IX, X, XI, XII, CAR and NCR
Storm Surge/Flood	Typhoon Quiel (Nalgae)	September 26-October 2, 2011	Manila Bay and Ilocos Sur; Regions I, II, III, CAR
Storm Surge/Flood	Typhoon Pedring (Nesat)	September 24-28, 2011	Coastal areas of Manila Bay; NCR, CAR, Regions I, II, III, IV-A, IV-B, V, VI
Flood/ Rain-induced landslide /Severe Wind	Typhoon Kabayan (Muifa)	July 28-August 5, 2011	Regions I, III, IV-A, VI, VII, NCR
Flood/ Rain-induced landslide /Tornado	Tropical Storm Juaning (Nock-Ten)	July 25-28, 2011	Regions III, IV-A, IV-B, V, VII, VIII, NCR
Flood/ Rain-induced landslide /Severe Wind	Tropical Storm Falcon (Meari)	June 21-25, 2011	Regions I, II, III, NCR
Flood	Tropical Storm Egay (Haima)	June 14-20, 2011	Regions III, NCR
Flood/ Rain-induced landslide	Tropical Storm Dodong (Sarika)	June 9-10, 2011	Regions I, II, III, CALABARZON, MIMAROPA
Flood	Tropical Storm Ester (Dianmu)	August 3-5, 2010	Regions III, NCR
Flood	Tropical Storm Caloy (Chanthu)	July 19-20, 2010	Region III
Flood/Severe Wind/ Rain-induced landslide	Typhoon Basyang (Conson)	July 12-15. 2010	Regions III, IV-A, V, NCR
Flood	Typhoon Santi (Mirinae)	October 28-November 1, 2009	Regions III, IV-A, IV-B, V, NCR
Storm Surge/Flood/ Rain-induced landslide	Typhoon Pepeng (Parma)	September 29-October 10, 2009	Regions I, II, III, IV-A, IVB, V, VI, IX, XII, ARMM, CAR and NCR; Landslide: Sitio Little Kibungan, Puguis in La Trinidad, Mankayan, Buguias, Tublay,

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
			Sablan, Baguio City, Benguet; Tadian, Mountain Province; Flood - San Manuel, Lingayen, Umingan, Tayug, San Nicolas, Natividad, Sta. Maria, Balungao, Rosales, Bautista, Bayambang, Pangasinan
Flood	Typhoon Ondoy (Ketsana)	September 24-27 , 2009	Regions I, II, III, IV-A, IVB, V, VI, IX, XII, ARMM, CAR and NCR
Flood	Typhoon Labuyo (Dujuan)	September 2-5, 2009	Regions III, VI, VII
Flood/Rain-induced landslide	Tropical Depression Maring (Mujigae)	September 8-9, 2009	Regions III, VI, VIII;Landslides: Olongapo City (in Purok 11 and 12 Gabaya St, Bo Barretto; Payapa St., Balik-Balik, Brgy Sta Rita; Johnson Ext., East Bajac-Bajac; and Purok 12, National Highway, Old Cabalan), National Highway along Brgy Putlan, Carranglan, Nueva Ecija, Sitio Camcaman, Brgy. Real, Calamba City
Flood/ Rain-induced landslide	Typhoon Kiko (Morakot)	August 7, 2009	Regions I, II, III, VI, XI, NCR, CAR
Flood/ Rain-induced landslide	Tropical Storm Jolina (Goni)	July 30- August 2, 2009	Regions I, II, III, IV-A, IV-B, VI, VIII, X, XII
Flood/ Rain-induced landslide	Tropical Storm Isang (Molave)	July 14-18, 2009	Regions I, III, IV-A, NCR
Flood/ Rain-induced landslide	Typhoon Feria (Nangka)	June 23-26, 2009	Regions III, IV-A, IV-B, V, VI, VII, VIII and NCR
Flood/ Rain-induced landslide	Typhoon Emong (Chan-hom)	May 6-10, 2009	Regions I, II, III, CAR
Flood/Severe Wind/ Rain-induced landslide	Typhoon Niña (Hagupit)	September 19-24, 2008	Regions I, II, III, IV-B, VI, X, CAR; Landslide and Flood: Baguio, La Trinidad, Itogon
Flood/Severe Wind/ Rain-induced landslide	Typhoon Karen (Nuri)	August 17-21, 2008	Regions I, III, CAR
Flood	Tropical Storm Julian (Kammuri)	August 3-5, 2008	Regions I, III
Storm Surge/Flood/ Rain-induced landslide	Typhoon Frank (Fengshen)	June 20-23, 2008	Regions I, III, IV-A, IV-B, V, VI, VII, VIII, IX, X, XI, XII
Storm Surge/Flood	Tropical Storm Cosme (Halong)	May 14-19, 2008	Zambales; Regions I, III,VI, VII, CAR
Flood/ Rain-induced landslide	Typhoon Mina (Mitag)	November 21-28, 2007	Regions I, II, III, IV-A, IV-B, V, VIII, CAR

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
Flood	Typhoon Ineng (Krosa)	October 1-7, 2007	Regions III, IV-A, IV-B, X, XII, & CAR
Flood/ Rain-induced landslide	Typhoon Egay (Sepat)	August 13-18, 2007	Regions I, II, III, IV-A, IV-B, V, NCR, CAR
Flood/ Rain-induced landslide	Tropical Storm Chedeng (Pabuk) / Dodong (Wutip)	August 5-10, 2007	Regions I, III, IV, CAR, NCR
Storm Surge/Flood	Typhoon Queenie (Chebi)	November 8-12, 2006	Isabela, Aurora and Nueva Ecija
Flood/Severe/ Rain-induced landslide	Typhoon Paeng (Cimaron)	October 27-30, 2006	Regions I, II, III, V, CAR; Landslide: Nueva Vizcaya, Benguet, Kalinga provinces
Flood/ Rain-induced landslide	Tropical Storm Henry (Prapiroon)	July 28- August 2, 2006	Regions I, II, III
Flood	Typhoon Glenda (Kaemi)	July 21-25, 2006	NCR, CAR, I, III, IV-A
Flood/Severe Winds/ Rain-induced landslide	Tropical Storm Florita (Bilis)	July 10-14, 2006	Regions I, III, IV, V, VI, XI, NCR, CAR
Flood	Tropical Depression Quedan (25W)	December 16-20, 2005	Regions I, II, III, IV-A, IV-B, V, VI, VIII, IX, CAR, CARAGA
Flood/ Rain-induced landslide	Typhoon Yoyong (Nanmadol)	Nov 30 - Dec 3, 2004	Regions I, II, III, IV, V, VIII, NCR and CAR
Flood	Tropical Depression Winnie	November 27-29, 2004	Regions I, II, III, IV, V, VIII, NCR and CAR
Flood/ Rain-induced landslide	Tropical Storm Violeta (Merbok)	November 22-26, 2004	Regions I, II, III, IV, V, VIII, NCR and CAR Rain-induced landslide
Flood	Typhoon Unding (Mulfa)	November 14-21, 2004	Regions I, II, III, IV, V, VIII, NCR and CAR
Flood/ Rain-induced landslide	Typhoon Marce (Aere)	August 20-24, 2004	Regions I, II, III, IV-A, NCR, CAR
Storm Surge/Flood	Typhoon Igme (Mindulle)	July 13-15, 2004	I, II, III, IV, V, VI, XII, CAR, ARMM
Flood/Severe Wind	Typhoon Onyok (Dujuan)	August 30-September 2, 2003	Regions III, NCR
Flood	Typhoon Etau (Kabayan)	August 4-5, 2003	Region III
Flood	Tropical Depression Milenyo (Vongfong)	August 11-14, 2002	Regions III, IV, V, VI, VII, VIII, NCR, X, CARAGA
Rain-induced landslide/ Flood/ Severe Wind	Combined effects of Typhoon Gloria (Chataan), Typhoon Inday (Halong), Typhoon Florita (Rammasun), and Severe Tropical	June 27-July 14, 2002	Regions I, III, IV, VI, XI, XII, NCR, CAR

Hazard	*Typhoon*	*Date/Year*	*Affected Provinces/Cities/ Municipalities*
	Storm Hambalos (Nakri)		
Flood	Tropical Depression Jolina (Tropical Storm Fitow)	August 16-19, 2001	Region III
Storm Surge/Flood	Typhoon Feria (Utor)	July 2-7, 2001	CAR, NCR, CARAGA, Regions I, II, III, IV, V, VI, VIII, IX & X
Flood	Typhoon Seniang (Bebinca)	October 31-November 5, 2000	NCR, CAR, III, IV, V
Flood/Severe Wind/ Rain-induced landslide	Typhoon Reming (Xangsane)	October 26-November 1, 2000	NCR, CAR, Regions I, II, III, IV, V, VI, VIII
Flood/ Rain-induced landslide	Typhoon Edeng (Kai-Tak)	July 3-8, 2000	CAR, NCR, Regions I, III, IV, VI
Flood	Tropical Storm Biring (Longwang)	May 18-19, 2000	NCR, Region III

Source: National Disaster Risk Reduction and Management Council (NDRRMC) Situational Reports from 2000 to 2023; JICA (1990-2012) historical records of typhoons and flood damage.

Climate-Related Risks

The study identified several climate-related hazards posing risks to the municipalities of Baler and San Luis within the watershed. These hazards include typhoons, flooding, rain-induced landslides, and storm surge. Notably, Baler appears to be more susceptible to flooding compared to San Luis. Table 4 and figure 2 provide detailed breakdown of barangays in Baler and San Luis that are high susceptibility.

Table 4: Barangays in Baler and San Luis that are susceptible to flooding.

Variables	*Barangays*	
Susceptible to flooding	*Baler*	*San Luis*
	Barangay V	Bacong
	Calabuanan	Barangay I
	Pingit	Barangay II
	Sabang	Seniong Senior
	Zabali	San Isidro
		Zarah
Population exposed to high flood susceptibility	2.8% population	0.6% population
Built up areas exposed to high flood susceptibility	1.58%	3.86%
Agriculture areas exposed to high flood susceptibility	9.15%	0

Source: Aurora Province and University of the Philippines Los Banos, 2023.

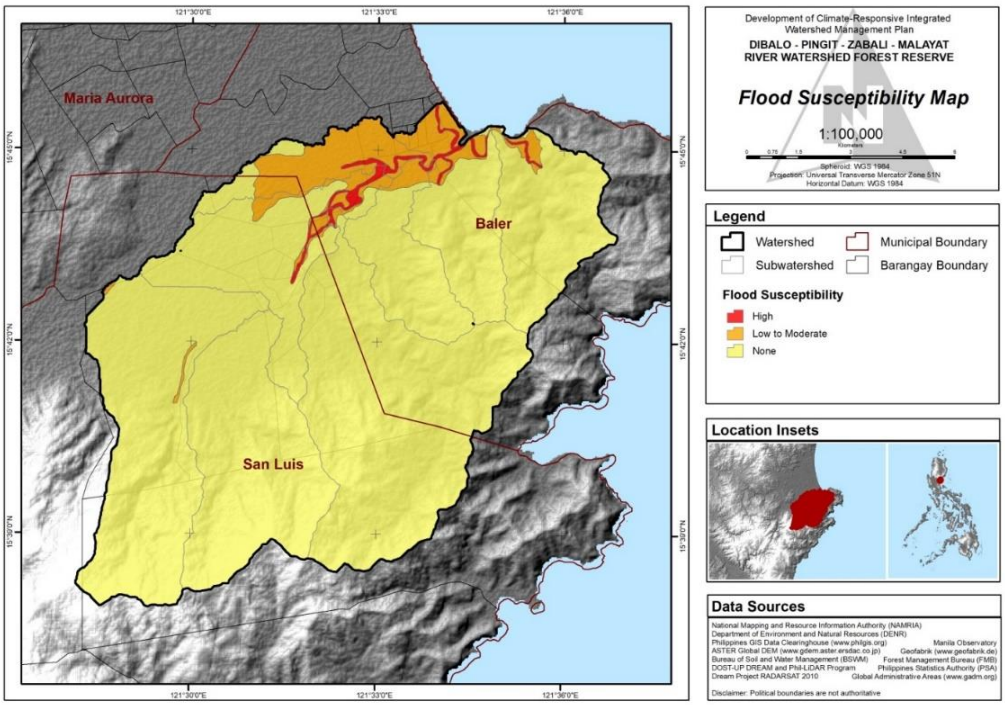

Figure 2: Flood susceptibility map of DPZM River Watershed
(*Source*: Aurora Province and University of the Philippines Los Banos, 2023)

Forest Decline and Land Cover Change

Evaluating the overall land cover dynamics between 1988 and 2020 shows that closed and open forests are the predominant land cover in DPZM River Watershed, however these forests are under increasing pressure primarily from anthropogenic influences including their main livelihood, which is agriculture (LCCAP San Luis, 2019). As shown in table 6, the percentage of the closed and open forests declined significantly. Forest cover dropped from 34% and 37% in 1988 to 40% and 14% in 2020 (Table 6). The rate of forests loss in DPZM were -31% year^{-1} (1988-2003), and -9% year^{-1} (2015-2020) for open forest, and -11% year^{-1} (2010-2015) for closed forest, respectively. Meanwhile, the annual crop (9%), built-up area (3%) and perennial crop (30%) registering large gains in area from 1988 to 2003. Thus, over a decade, a landscape dominated by dense forest evolved into a landscape that contained much more built-up and agricultural land cover. An increase in built-up class apparently due to the pressure exerted by increases in population. Similar deforestation trends have also appeared in other tropical and temperate regions of the world (Robeson, Thapa and Saikia, 2016). The decline in forest cover observed from 1988 to 2020 (Figure 3) presents a significant challenge. However, it also offers an opportunity for local and national government agencies in Baler and San Luis, Aurora province, to champion science-based watershed management strategies. By prioritizing sustainable practices, we can ensure the health and well-being of the DPZM River Watershed for future generations. This requires continued monitoring of land cover changes and a commitment to implementing effective interventions. By working collaboratively with local communities, we can find solutions that balance economic development with environmental protection.

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Uncontrolled land development for agriculture, residences, commerce, and industry can significantly contribute to environmental degradation if such practices remained unchecked. The conversion of agricultural land for non-agricultural uses, such as commercial buildings, housing projects, and recreational facilities, displaces farming households. Unfortunately, this often leads farmers to cultivate marginal upland areas, which are more susceptible to erosion and environmental damage.

Table 6: Land cover area, percentage, and annual rate of change of the Dipaculao-Pingit-Zabali-Malayat River Watershed Forest Reserve.

Land Cover Class	*Area (ha)*					*Cover Change between Periods (%)*					*Annual Rate of Change (%)*				
	1988	*2003*	*2010*	*2015*	*2020*	*1988-2003*	*2003-2010*	*2010-2015*	*2015-2020*	*1988-2020*	*1988-2003*	*2003-2010*	*2010-2015*	*2015-2020*	*1988-2020*
Annual Crop	506.39	1,608.83	1,095.77	999.37	1,173.80	8.48	-3.95	-0.74	1.34	5.14	7.71	-5.49	-1.84	3.22	2.63
Built-up	0.00	118.49	228.26	303.98	455.16	0.91	0.84	0.58	1.16	3.50	-	9.37	5.73	8.07	-
Closed Forest	4,451.99	6,831.61	7,386.54	4,202.74	5,207.76	18.31	4.28	-24.50	7.73	5.82	2.85	1.12	-11.28	4.29	0.49
Grassland/Shrubs	374.45	82.24	148.58	0.00	197.42	-2.25	0.51	-1.14	1.52	-1.36	-10.11	8.45	-	-	-2.00
Inland Water	0.00	90.02	86.91	58.23	180.26	0.69	-0.02	-0.22	0.94	1.39	-	-0.50	-8.01	22.60	-
Mangrove Forest	0.00	0.00	3.84	12.54	26.56	0.00	0.03	0.07	0.11	0.20	-	-	23.65	15.01	-
Open Forest	4,820.66	47.94	0.00	2,997.65	1,862.56	-36.72	-0.37	23.07	-8.74	-22.76	-30.74	-	-	-9.52	-2.97
Perennial Crop	2,842.84	4,216.31	4,043.82	4,419.92	3,890.91	10.57	-1.32	2.89	-4.07	8.07	2.63	-0.60	1.78	-2.55	0.98

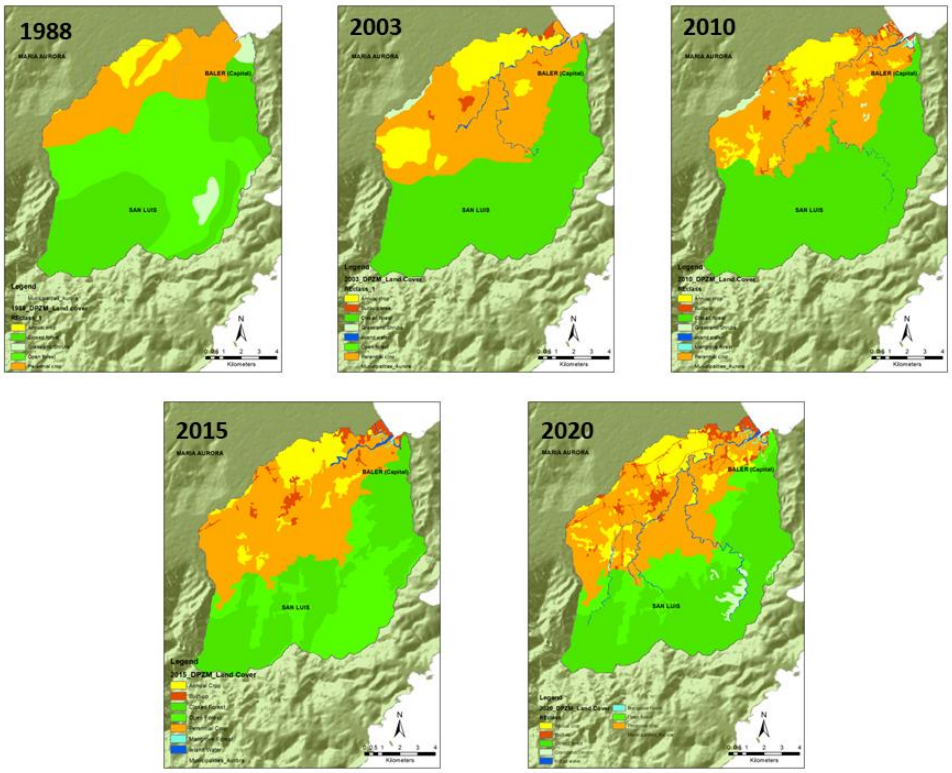

Figure 3: LULC maps for 1988, 2003, 2010, 2015 and 2020 in Dipaculao-Pingit-Zabali-Malayat River Watershed Forest Reserve, Baler, San Luis, Aurora. (Source: GIZ and NAMRIA)

Landscape metrics and fragmentation analysis in the DPZM River Watershed

The utmost important indicators of landscape fragmentation are the number of patches and the change in the number of smaller patches, as measured by patch density (Echeverria *et al*., 2006; Garcia *et al.*, 2020; Kammerbauer and Ardon, 1999; Robeson, Thapa and Saikia, 2016; Southworth, Munroe and Nagendra, 2004). This can have significant negative impacts on biodiversity, ecological processes, and ecosystem services. An analysis of DPZM Watershed revealed an erratic trend from 1988 to 2015 (Table 7 and Figure 4). However, from 2015 to 2020 the NP, ED, and PAFRAC increased significantly. Conversely, the MPS showed a decreasing trend with annual change rate of -9%. These recent trends clearly indicate that the health of the watershed is increasingly compromised, thereby threatening its ability to provide ecosystem services and ultimately undermine its resilience.

Table 7: Spatial metrics of the DPZM River Watershed Forest Reserve

Landscape Metrics	*1988*	*2003*	*2010*	*2015*	*2020*	*Annual Rate of Change (%) (1988-2020)*
Number of patches (NP)	14	47	234	70	249	8.99
Edge density (ED m/ha)	6.98	9.94	19.11	18.29	33.83	4.93
Mean patch size (MPS ha)	928.26	276.48	55.53	185.63	52.18	-9.00
PAFRAC	1.12	1.19	1.36	1.25	1.38	0.65

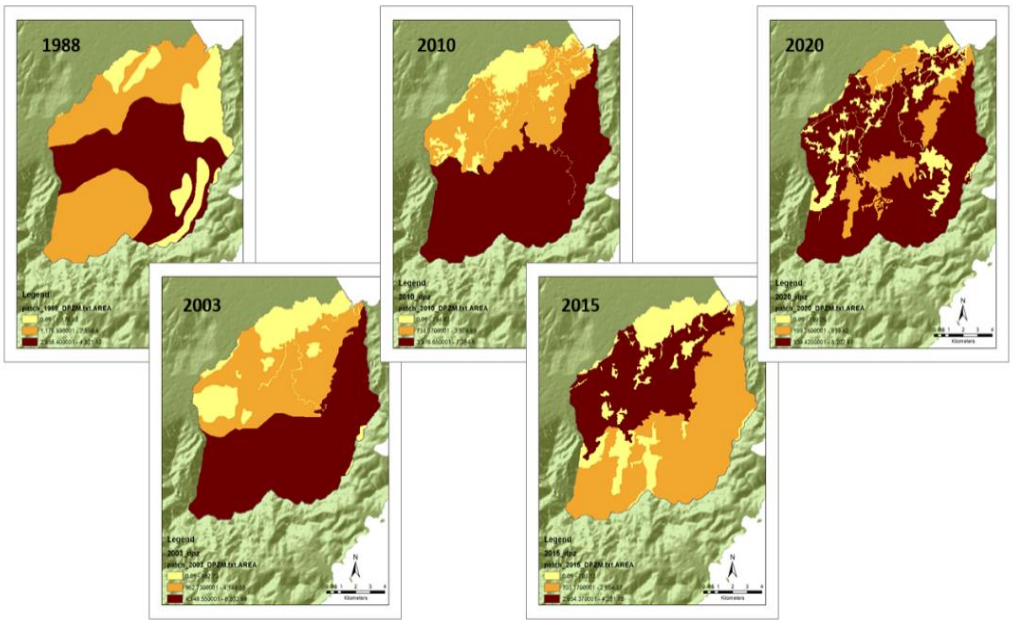

Figure 4: Patch maps of landscape fragmentation from 1988-2020 in Dipaculao-Pingit-Zabali-Malayat River Watershed Forest Reserve, Baler and San Luis, Aurora

Conclusions

Aurora province faces the challenge of balancing development with environmental sustainability in the face of climate change. This study examines the two critical aspects of this challenge within the DPZM river watershed: increasing frequency and intensity of typhoons, and the ongoing transformation of land cover driven by human activities. The analysis of historical typhoon data underscores the critical importance of disaster preparedness, mitigation, and response measures in Aurora province. By understanding and addressing the vulnerabilities highlighted by these recurring hazards, authorities can better safeguard lives and livelihoods, enhance infrastructure resilience, and foster community resilience in the face of future climate-related challenges. Continued monitoring and adaptation strategies will be essential in minimizing the adverse impacts of typhoons and other natural disasters on the province and its residents.

The analysis of land cover dynamics in the DPZM River Watershed from 1988 to 2020 reveals significant transformations, primarily driven by anthropogenic activities, particularly agriculture. The predominant closed and open forests, critical for ecological balance and local livelihoods, have faced substantial declines, with closed forest decreasing by 11% annually from 2010 to 2015 and open forest by 31% annually from 1988 to 2003. This loss has been accompanied by notable increases in annual crop (9%), built-up area (3%), and perennial crop (30%) categories.

The shift towards more built-up and agricultural land reflects increasing human population pressures, which have escalated over the decades. This trend emphasizes the urgent need for science-based watershed management strategies by local government units in Baler and San Luis, Aurora province. Without effective intervention, the ongoing decline in forest cover poses significant risks to future generations, including landscape fragmentation and associated ecological impacts.

Monitoring indicators such as patch density and changes in patch sizes highlight the progressive fragmentation of the landscape, particularly evident from 2015 to 2020. Despite fluctuations in certain metrics over earlier periods, recent years have shown consistent increases in fragmentation indices (NP, ED, PAFRAC) alongside a decline in mean patch size (MPS). In light of these findings, concerted efforts are required to mitigate further degradation through sustainable land use practices, afforestation initiatives, and enhanced conservation measures. Addressing these challenges comprehensively will be crucial for preserving the ecological integrity and resilience of the DPZM River Watershed in the face of ongoing development pressures.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*
Conceived and designed the research or analysis	Yes	Yes	Yes	No
Collected the data	Yes	No	Yes	No
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	No
Critical revision of the article/paper	Yes	Yes	Yes	No
Editing of the article/paper	Yes	Yes	Yes	Yes
Supervision	Yes	Yes	No	Yes
Project Administration	No	Yes	No	No
Funding Acquisition	No	Yes	No	No
Overall Contribution Proportion (%)	40	30	20	10

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

Research on Indigenous Peoples and/or Traditional Knowledge
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Research involving Plants
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the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

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(Optional) PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
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